ASUU Journal of Science
A Journal of Research and Development
Vol. 2, No. 1, December, 2014 pp. 55-78

VTEC VARIABILITY AT EQUATORIAL AND HIGH LATITUDES DURING DIFFERENT SOLAR ACTIVITIES

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Abstract

Variability studies of vertical total electron content (VTEC) over the equatorial and high latitude regions are presented in this paper. The variability is presented for 2001, a year of high solar activity (HSA), and 2009, a year of low solar activity (LSA), using data from four Global Positioning System (GPS) receivers located at Kangerlussuag (66.99°N, 309.05°E), Greenland, Fairbanks (64.98°N, 212.50°E), U.S.A., Dededo Guam (13.59°N, 144.87°E) and Mbarara Uganda (0.60°S, 30.74°E). VTEC values were grouped into four seasons namely March Equinox (February, March, April), June Solstice (May, June, July), September Equinox (August, September, October), and December Solstice (November, December, January). VTEC increased from 0600 h LT and reached its maximum value during 1300 h - 1500 h LT during all seasons and at all locations. For the equatorial stations, during LSA, the variability was generally lower than 40% of median, except during September equinox at Mbarara. The result of this study shows a solar activity dependence of variability index (VI) at equatorial latitude, since VTEC and VI are generally higher during HSA than LSA in all the months considered. VI exhibits irregular diurnal pattern during all the seasons, and varies mostly from 10% to 40% at equatorial latitude during LSA and varies from 10% to 100% at equatorial region during HSA and high latitude during both LSA and HSA.

Keywords: TEC; Solar Activity; Equatorial Ionosphere; IRI

1.0 Introduction

The day-to-day variability of total electron content (TEC) is driven mostly by solar and geomagnetic activities. This day-to-day variability has been studied by several researchers at different sectors (Adewale *et al.*, 2012; Bagiya *et al.*, 2009; Ezquer *et al.*, 2004; Ezquer *et al.*, 2002). Ezquer *et al.* (2004) studied TEC behaviour in the American sector during high solar activity. Their result shows that the vertical total electron content (VTEC) values during equinox months are greater than those of solstice and that the highest VTEC values are observed at low latitude stations in the American sector. In general, they observed that variability during daylight hours is about 30% of median or less, and that of night time hours is greater than 30%. Lazo *et al.* (2004) observed that the periods of minimum solar activity lead to higher levels of the Interquartile Difference (IQ) variability over Havana (23°N, 278°E). The values of the Upper Quartile (UQ), Lower Quartile (LQ), and IQ variability are higher during equinox months at low and medium solar activity periods. These variability studies are useful for the development of ionospheric models for predicting VTEC. The most popular of these models is the International Reference Ionosphere (IRI) model.

Recently, Adewale *et al.* (2012) studied the diurnal, seasonal and latitudinal variations of VTEC over the equatorial region of the African continent in comparison with IRI-2007 derived TEC (IRI-TEC), using all three options (namely; NeQuick, IRI01-corr and IRI-2001). The result shows that some improvements are still required in order to obtain improved predictions of TEC over the equatorial region of the Africa sector. Similarly, Sethi *et al.* (2011) and Chauhan and Singh (2010) reported that some improvements are still required for an improved IRI-TEC prediction. Bilitza and Reinisch (2008) reported that IRI predictions are most accurate over the Northern mid-latitudes because of the generally high ionosonde density in this part of the globe.

The purpose of the present research is to compare VTEC variability observed at different latitudes, seasons and solar activities. The result of this study will increase our understanding of the dynamics of the equatorial and high latitude ionosphere and also provide information to improve the IRI model. It is important to include TEC variability prediction in the present IRI models because variability index will give satellite designers and communication engineers expected deviations from the average ionospheric conditions.

2.0 Methodology

The VTEC data used for this study were obtained from the University Navstar Consortium (UNAVCO) (www.unavco.org) websites. Table 1 shows the coordinates of the four stations used for this study.

The GPS-TEC analysis application software developed by Gopi Seemala of the Institute for Scientific Research, Boston College, U.S.A. is used to calculate VTEC from the observation data using a suitable mapping function. The mapping function S(E) is given by (Mannucci *et al.*, 1993)

$$S(E) = \frac{1}{\cos(z)} = \left\{1 - \left(\frac{R_E \times \cos(E)}{R_E + h_S}\right)^2\right\}^{-0.5} \qquad (1)$$

with

z = zenith angle of the satellite as seen from the observing station,

R_E = radius of the Earth,

E = the elevation angle in radians, and

h_s = the altitude of the thin layer above the surface of the Earth (taken as 350 km)

The monthly GPS Differential Code Biases (DCBs) for GPS satellites and receivers used in the calculation of VTEC, as determined by the Centre for Orbit Determination in Europe (CODE), were obtained from ftp://ftp.unibe.ch/aiub/CODE/.

In order to minimize the multipath effects on GPS data, an elevation angle cut off of 30Ú was used. This implies that VTEC corresponding to elevation angles less than 30.0Ú were removed from the analysis.

We have used VTEC values for March Equinox (MAREQUI) (February, March, April), June Solstice (JUNSOLS) (May, June, July), September Equinox (SEPTEMBER EQUINOX) (August, September, October), and December Solstice (DECSOLS) (November, December, January), for the year 2009 with an average sunspot number (*R*) of 3.1, to represent a period of low solar activity (LSA). For high solar activity (HSA), we used data from 2001 (which is close to the peak of the solar cycle), with an average sunspot number (*R*) of 111.0. The variability of VTEC data are quantified by Median (*MED*), Lower (*LQ*) and Upper (*UQ*) quartiles. The coefficient of variability index (*VI*) is statistically defined as:

$$VI = \frac{UQ - LQ}{MED} \times 100 \qquad (2)$$

3.0 Results

Figures 1–8 show the diurnal and seasonal variations of VTEC (upper quartile, median, and lower quartile) values during HSA (2001), and LSA (2009), for all the stations. The result shows that the median values of VTEC are higher during HSA period for all the seasons. Our result shows that the VTEC values observed at equatorial stations are greater than those observed at high latitude stations.

From all the seasons and locations considered, VTEC has lower values during nighttime compared with daytime values. For both LSA and HSA, VTEC generally decreases from 0000 h LT to a minimum value around 0600 h LT in the equatorial stations, after which it starts to increase gradually until it reaches its maximum value during 1400 h – 1500 h LT in all the seasons. However, in the high latitude stations, for both LSA and HSA, VTEC is fairly linear during 0000 h - 0700 h LT, after which it starts to increase until it reaches its maximum value during 1300 h - 1500 h LT in all the seasons.

Figures 9-16 show the variability index (*VI*) for all the stations. During LSA at the equatorial region, *VI* is mostly lower than 40% of median, except during SEPTEMBER EQUINOX at MBAR. However, at high latitude stations during LSA, *VI* is lower than 40% of median during June Solstice at all hours of the day in both stations and in other seasons it has values greater than 40 % of median during several hours of the day. During HSA in both equatorial and high latitude regions, *VI* is mostly below 80 % of median except at MBAR, FAIR and KELY during December Solstice. In general, the *VI* exhibits irregular diurnal pattern during all the seasons, and varies mostly from 10% to 100 % of median values

4.0 Discussion

VTEC are higher at low latitude stations than at high latitude stations during both LSA and HSA period. This is primarily because the low-latitude ionosphere is strongly influenced by electromagnetic forces that arise because the geomagnetic field runs horizontally over the magnetic equator and that the rate of loss is greater than the rate of production at high latitude. Asymmetric heating of high latitude and equatorial latitude (Rishbeth and Gariott, 1969; Shweta *et al.*, 2010) is believed to be responsible for neutral gases being transported from high latitude ionosphere to equatorial latitude, which increases the electron concentration at the equatorial region.

In all the stations, VTEC are higher during HSA period. This is because ionospheric electron content increases with increasing solar activity (Rishbeth, 1964; Stubbe, 1964).

Our result shows that VTEC has lower values during nighttime compared with daytime values in all the months considered, with maximum value during 1400 h –1500 h LT. These peaks have been known to be associated to higher production of solar radiations during daytime (Fejer *et al.* 1991; Lee and Reinisch, 2006).

Although our result shows a solar activity dependence of *VI*, the diurnal and seasonal variations behave irregularly. It is expected that the information presented in this work will assist in the development of a model for ionospheric variability.

Conclusions

In this paper, the VTEC observations obtained from GPS signals received at four stations in the equatorial and high latitude sectors were analyzed to provide diurnal variation, seasonal variation and variability index of VTEC. VTEC are generally higher during HSA period for all the seasons. VTEC has lower values during nighttime compared with daytime values. TEC values generally increases from 0600 h LT in all the seasons and reaches its maximum value during 1400 h – 1500 h LT. Daytime values of VTEC are greater in March equinox than during September equinox while the lowest values are observed during June solstice. Our analysis shows that variability of VTEC in general, does not show any systematic diurnal pattern during LSA and HSA. The variability of VTEC in general, during LSA period was found to be lower than HSA period.

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Table 1: Coordinates of GPS receiver locations

	Station	Geographic	
Stations	Code	Latitude°N	Longitude°E
Kangerlussuaq, Greenland	KELY	66.99	309.05
Fairbanks, USA	FAIR	64.98	212.50
Dededo, Guam	GUAM	13.59	144.87
Mbarara, Uganda	MBAR	-0.60	30.74

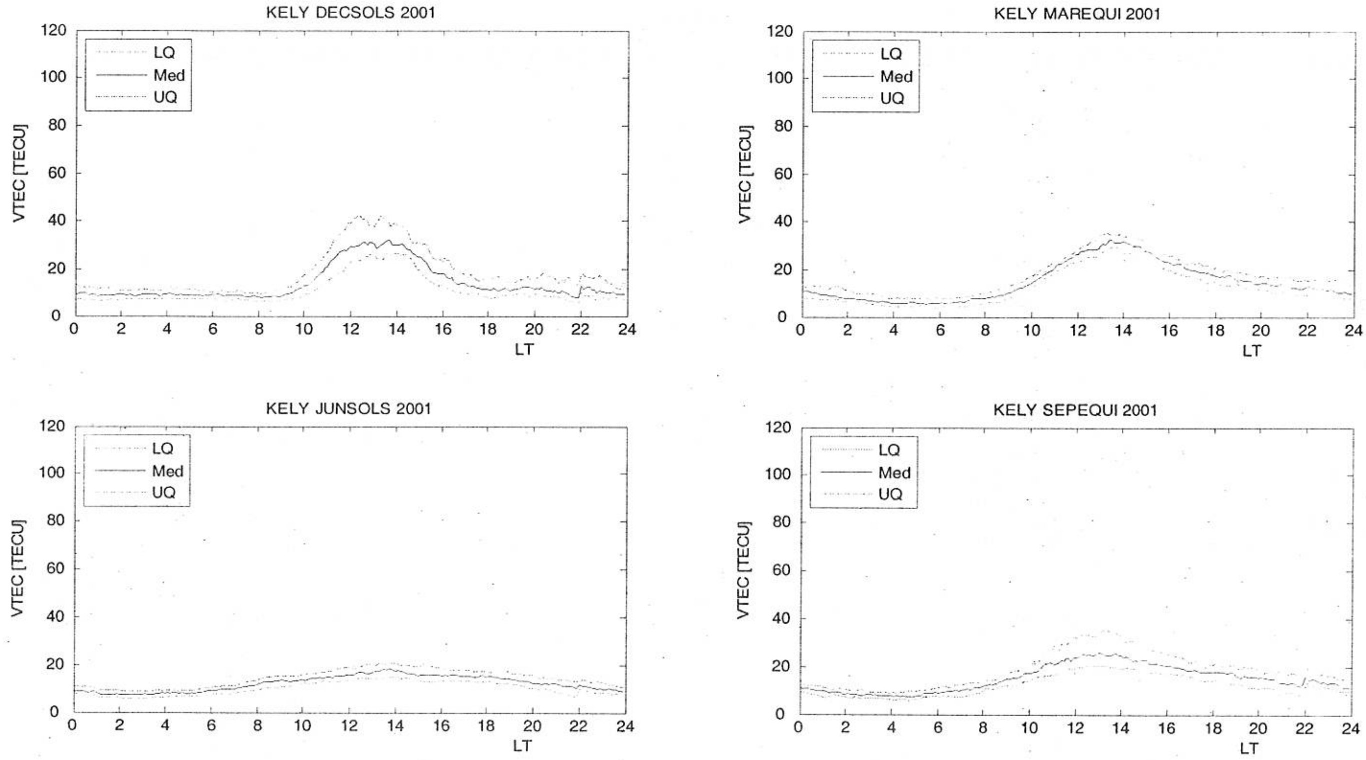

Figure 1: Diurnal variation of median VTEC, Upper quartile and Lower quartile for KELY during HSA

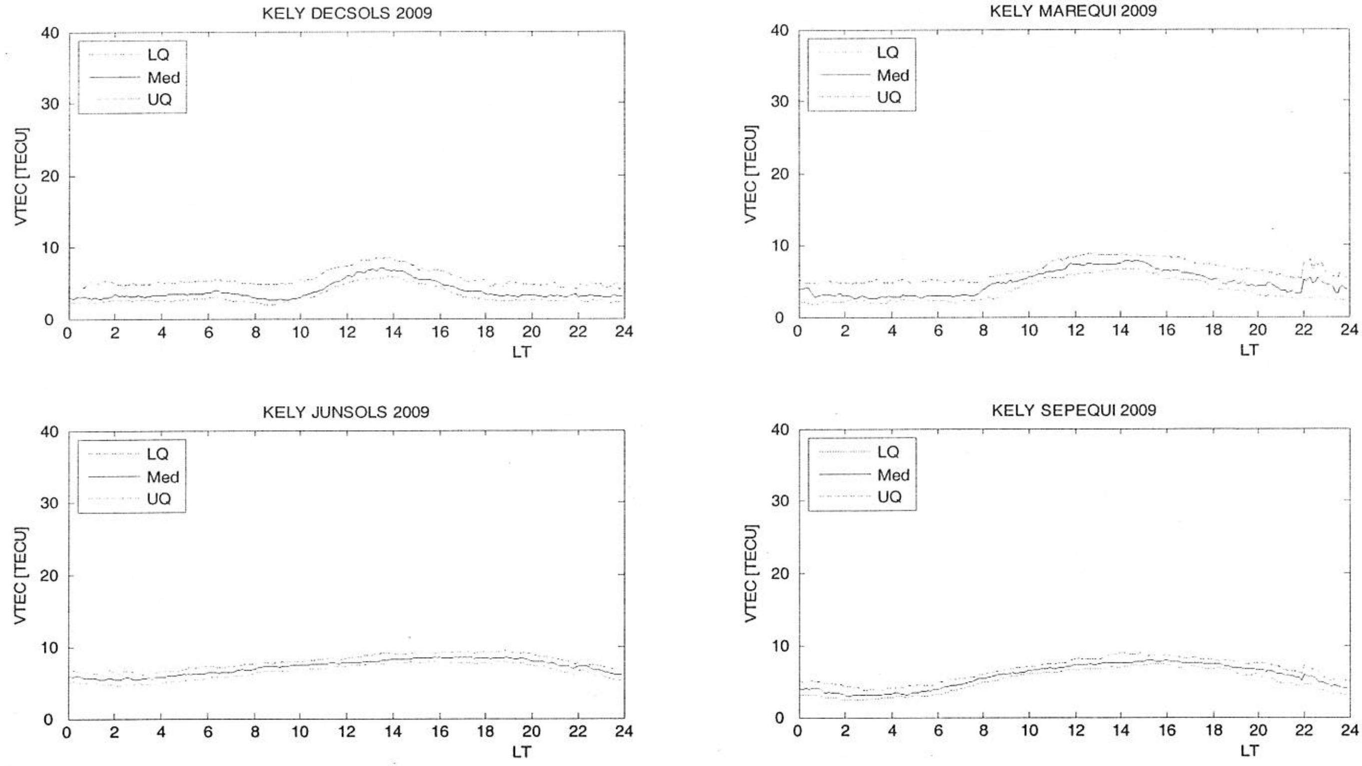

Figure 2: Diurnal variation of median VTEC, Upper quartile and Lower quartile for KELY during LSA

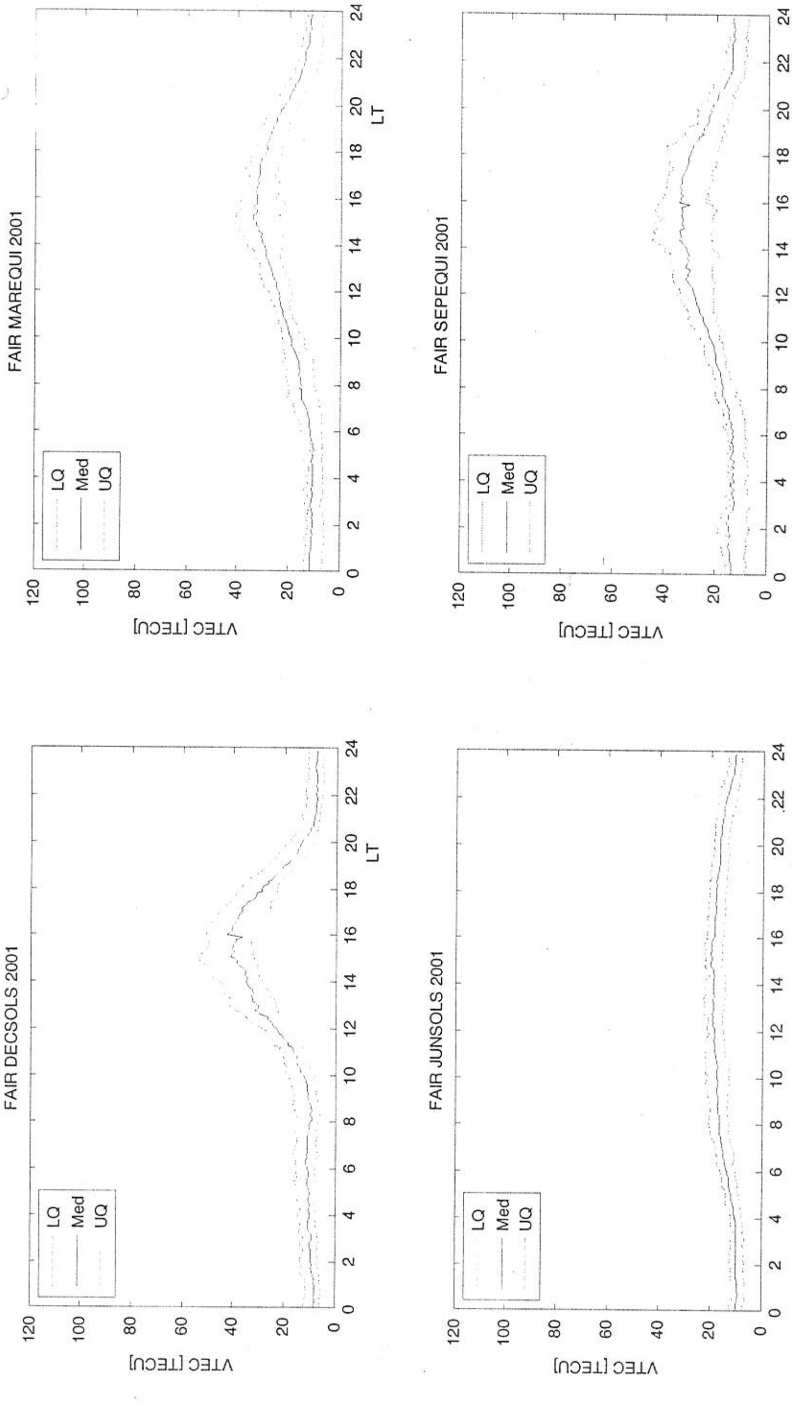

Figure 3: Diurnal variation of median VTEC, Upper quartile and Lower quartile for FAIR during HSA

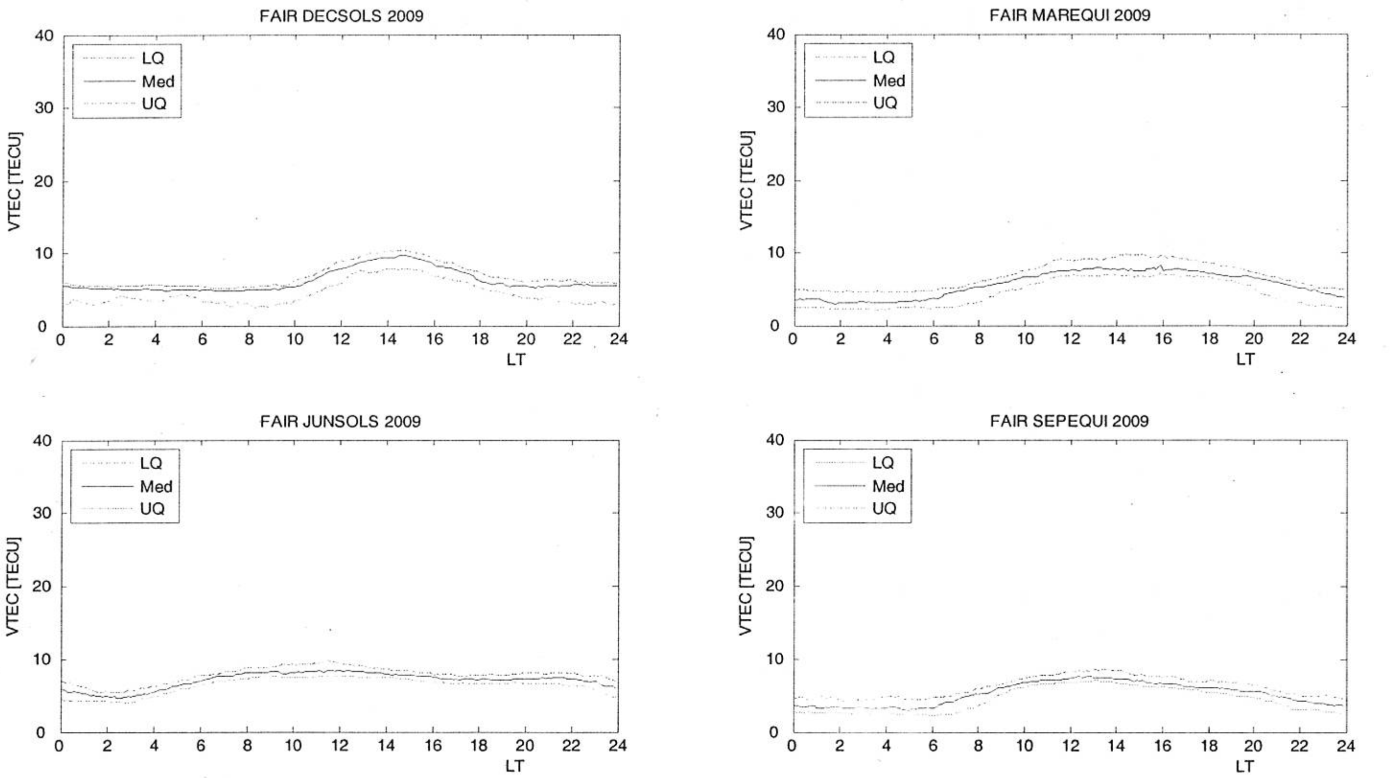

Figure 4: Diurnal variation of median VTEC, Upper quartile and Lower quartile for FAIR during LSA

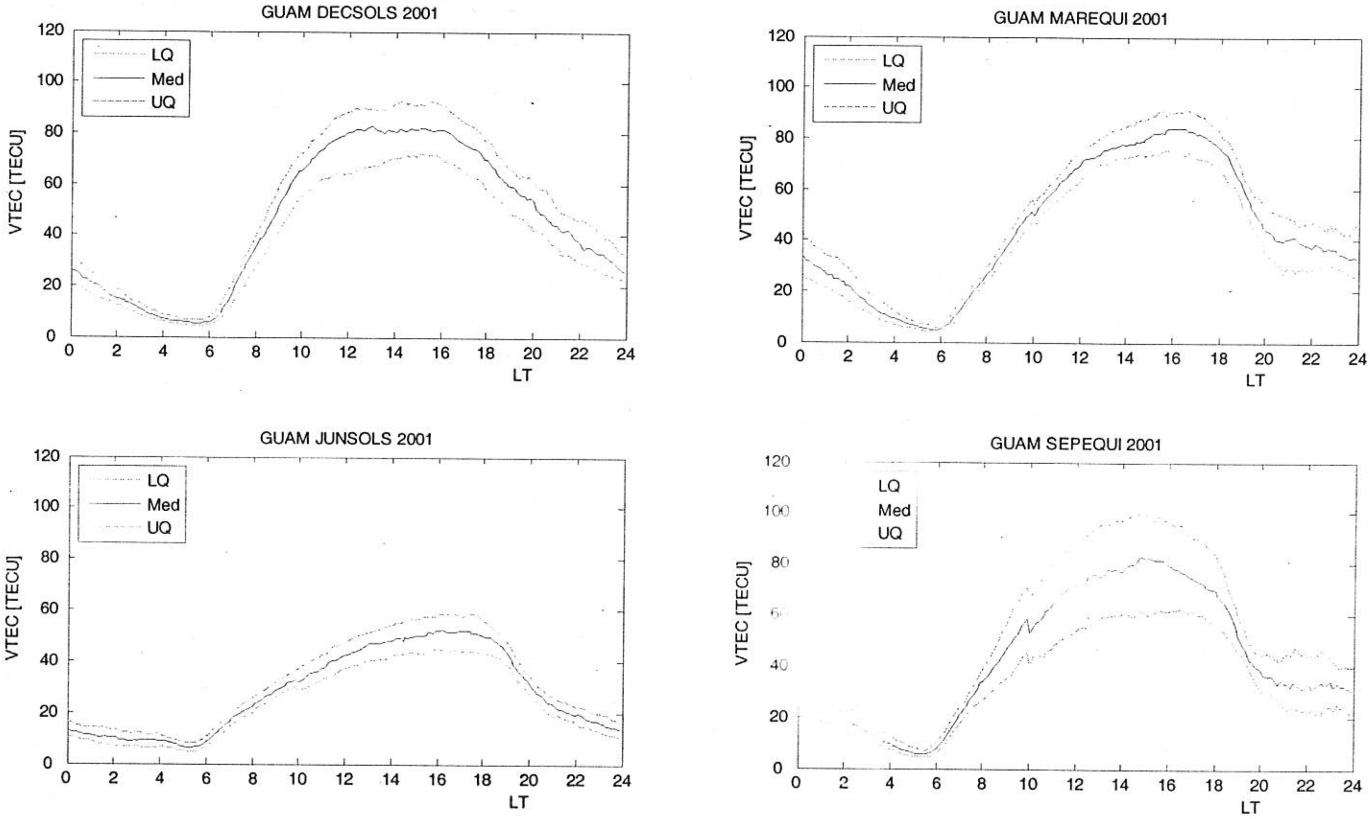

Figure 5: Diurnal variation of median VTEC, Upper quartile and Lower quartile for GUAM during HSA

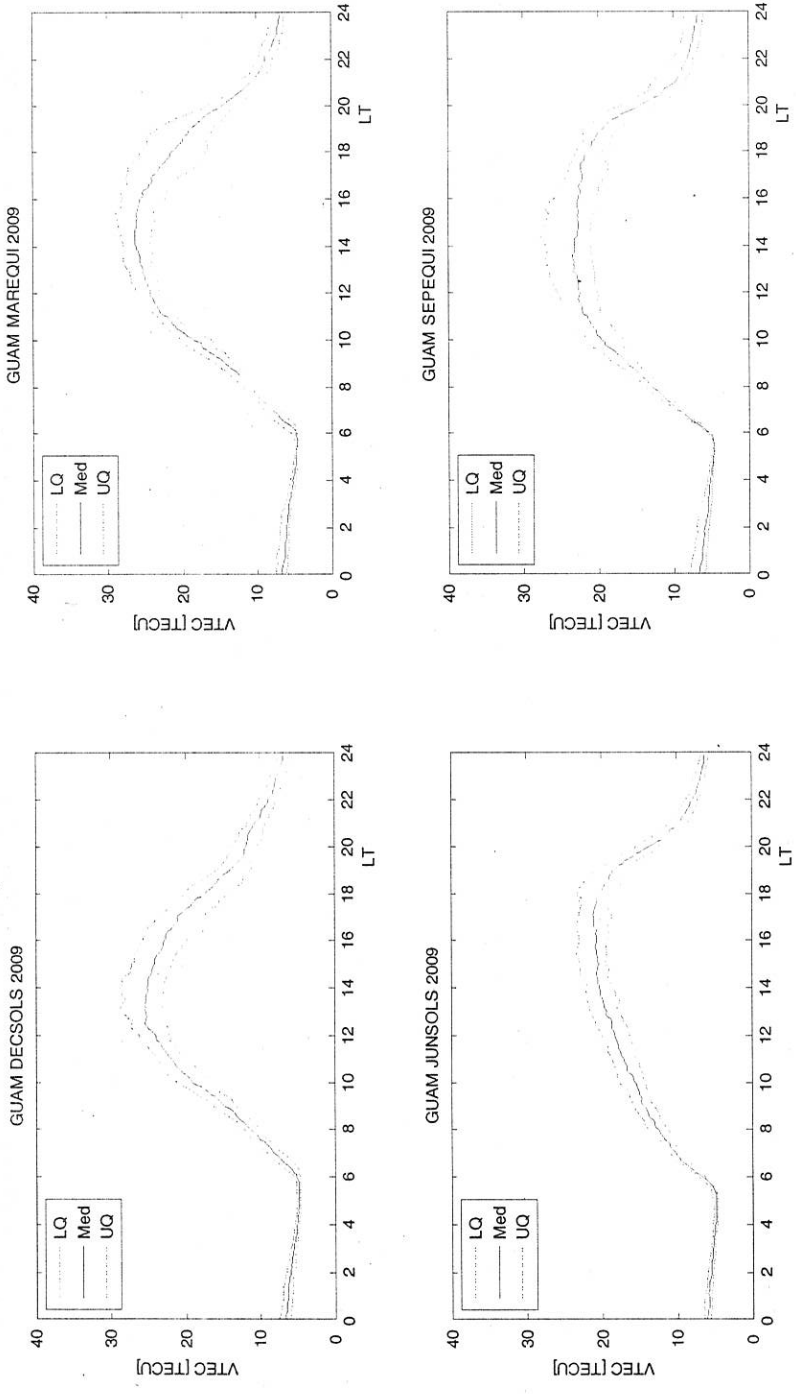

Figure 6: Diurnal variation of median VTEC, Upper quartile and Lower quartile for GUAM during LSA

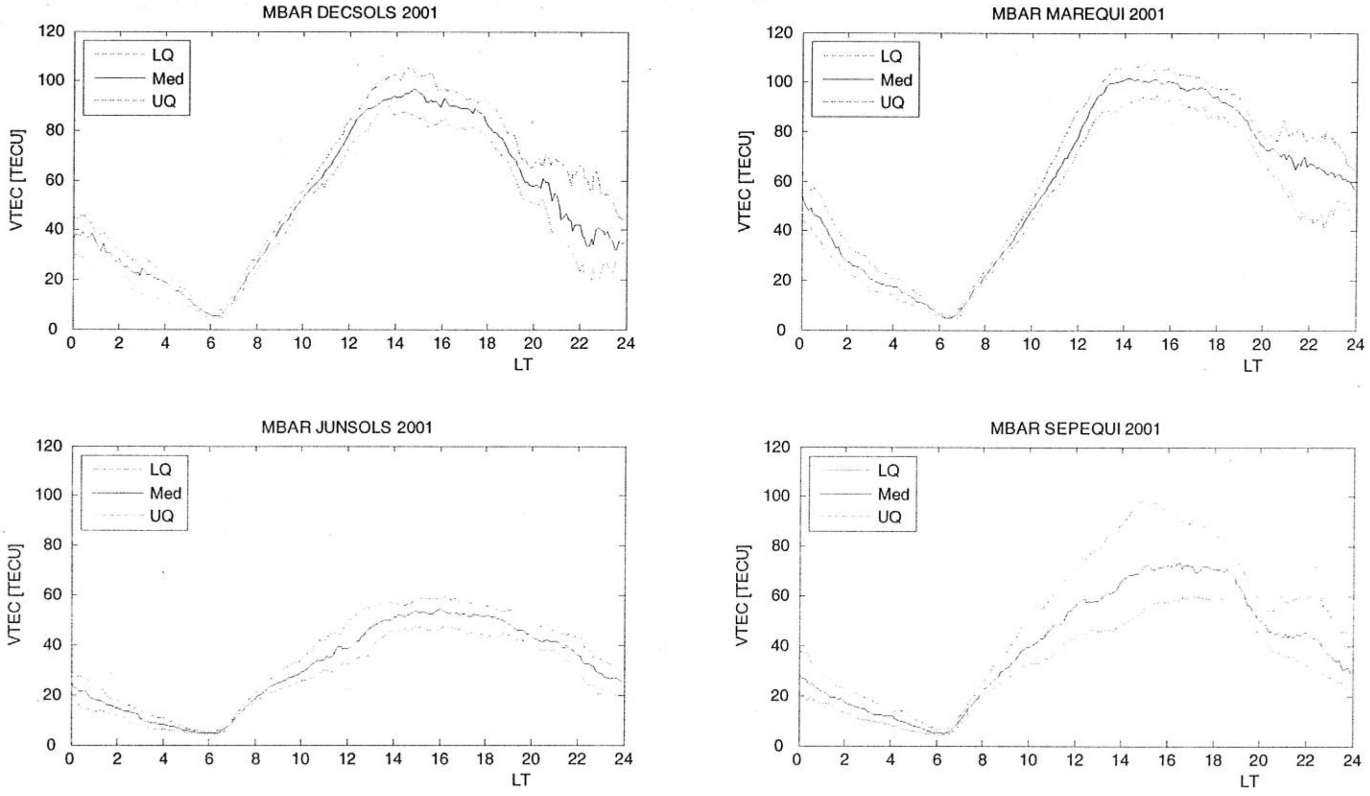

Figure 7: Diurnal variation of median VTEC, Upper quartile and Lower quartile for MBAR during HSA

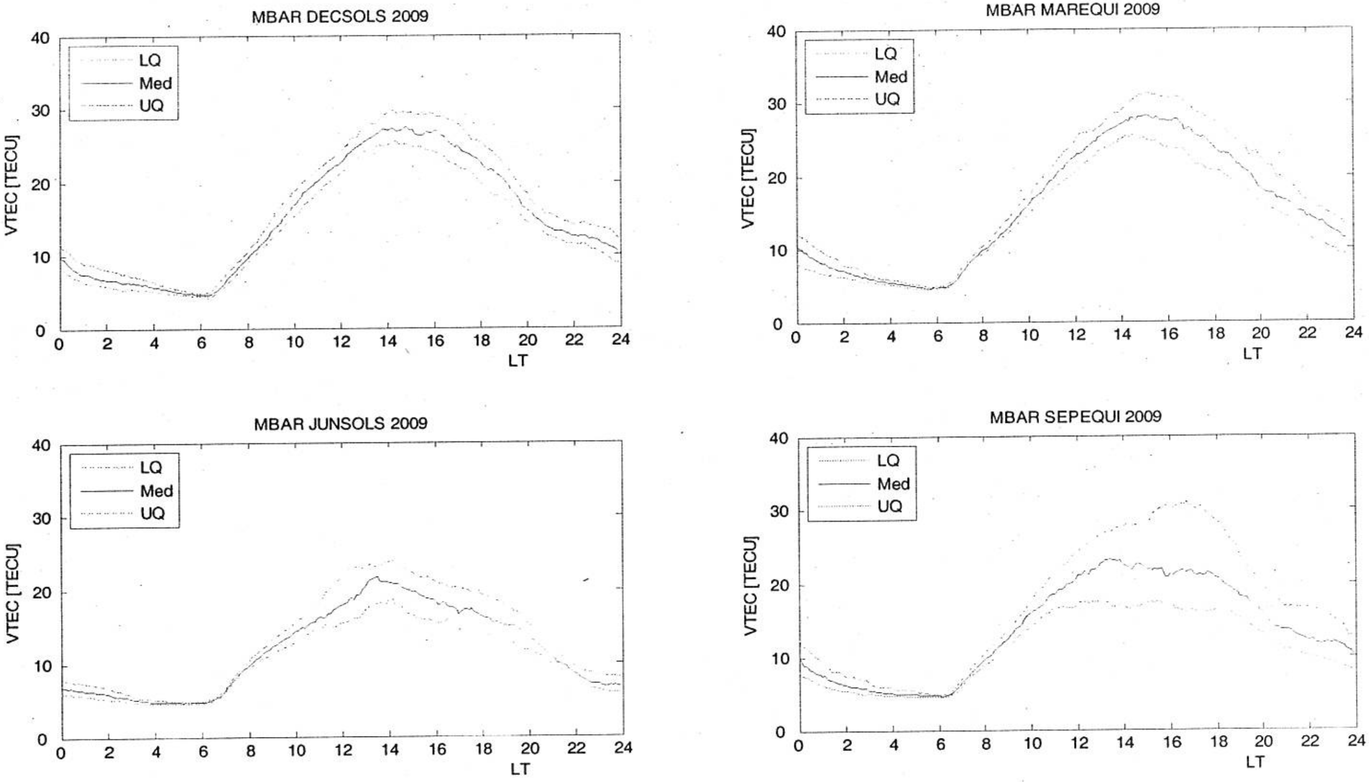

Figure 8: Diurnal variation of median VTEC, Upper quartile and Lower quartile for MBAR during LSA

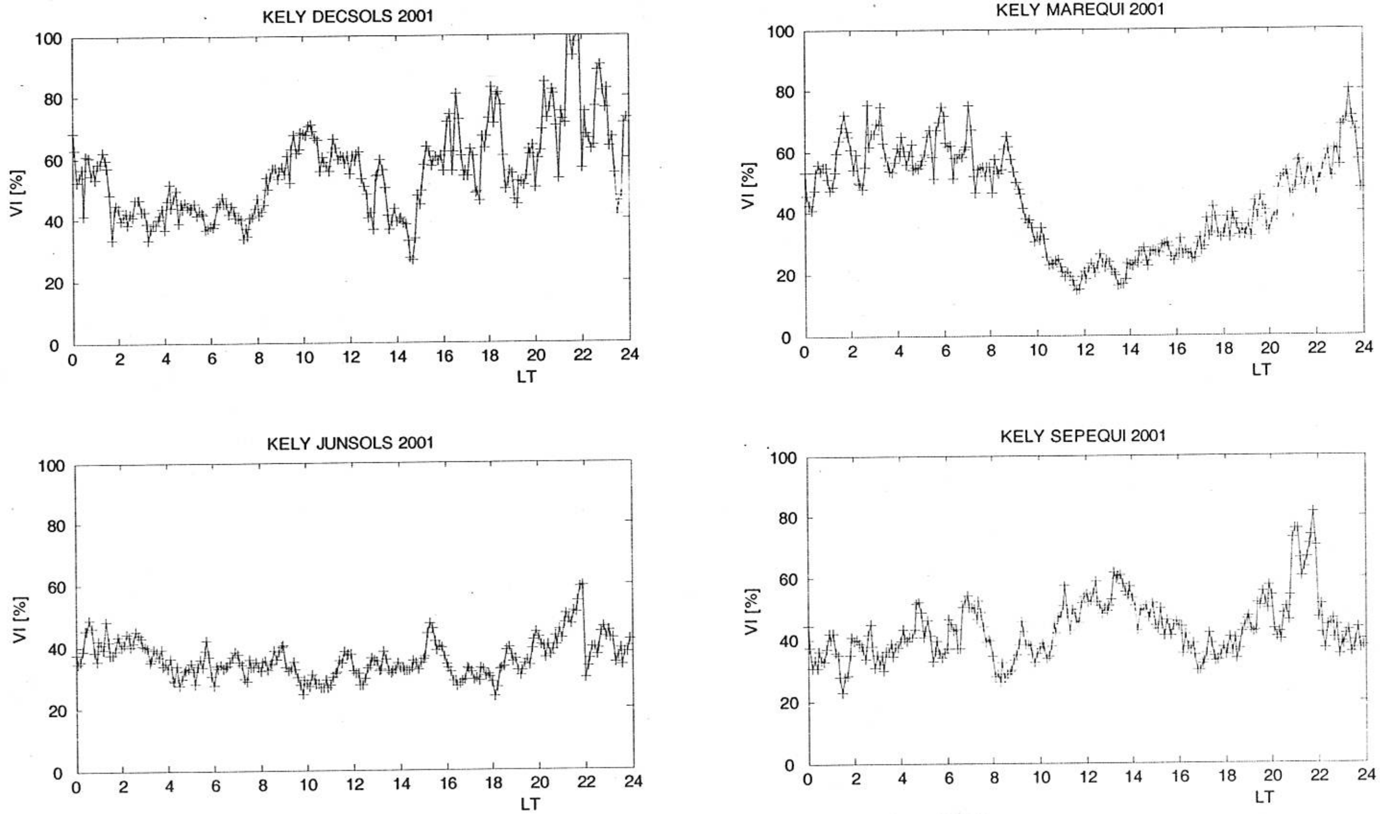

Figure 9: Variability index for KELY during HSA

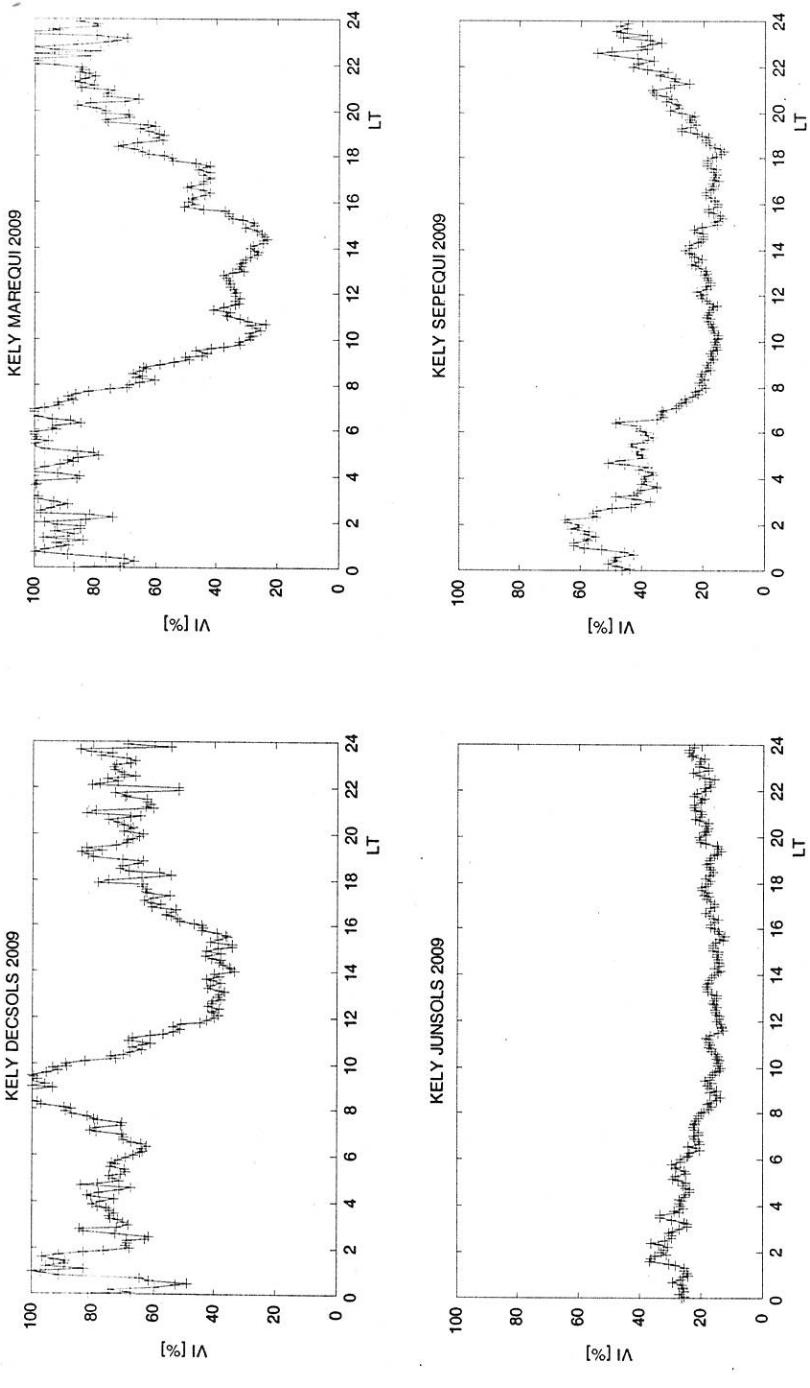

Figure 10: Variability index for KELY during LSA

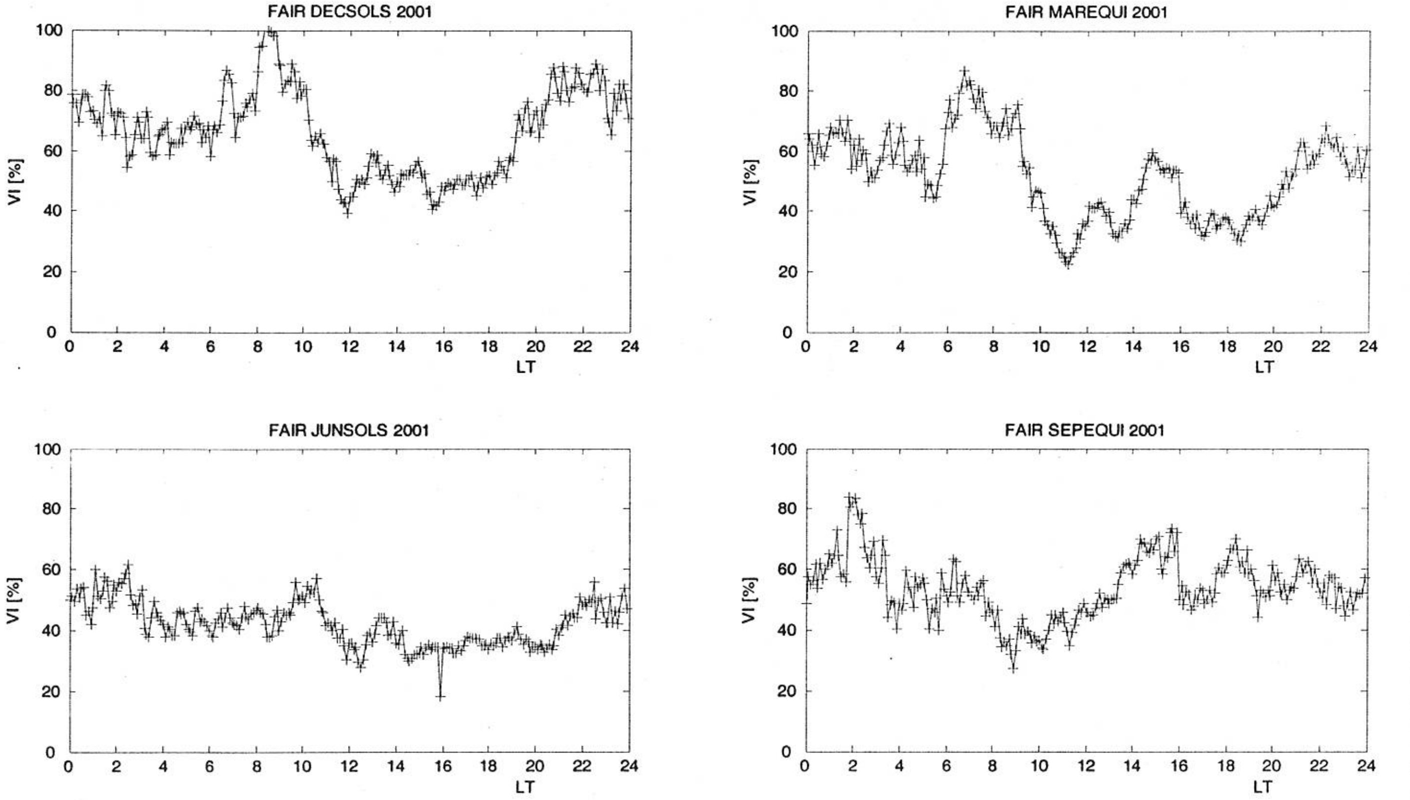

Figure 11: Variability index for FAIR during HSA

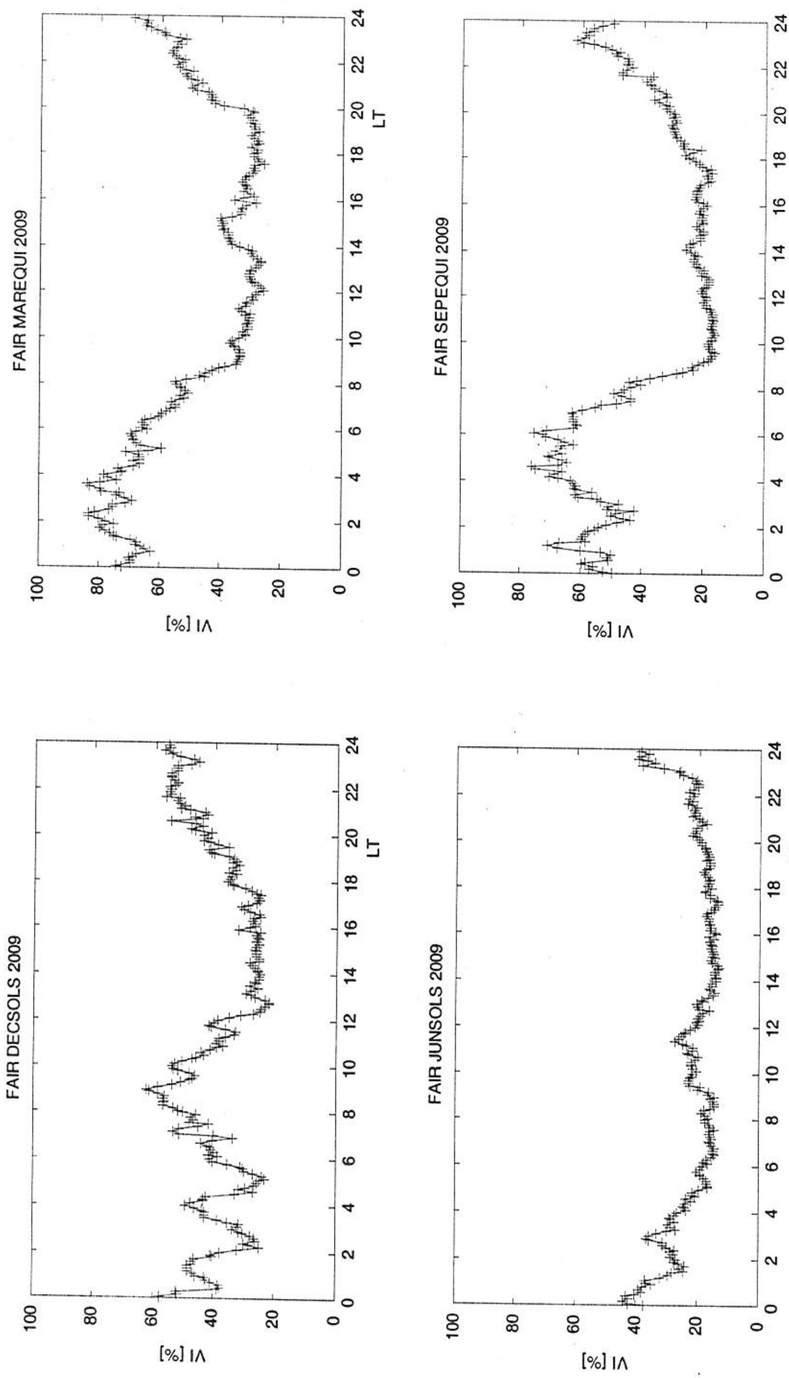

Figure 12: Variability index for FAIR during LSA

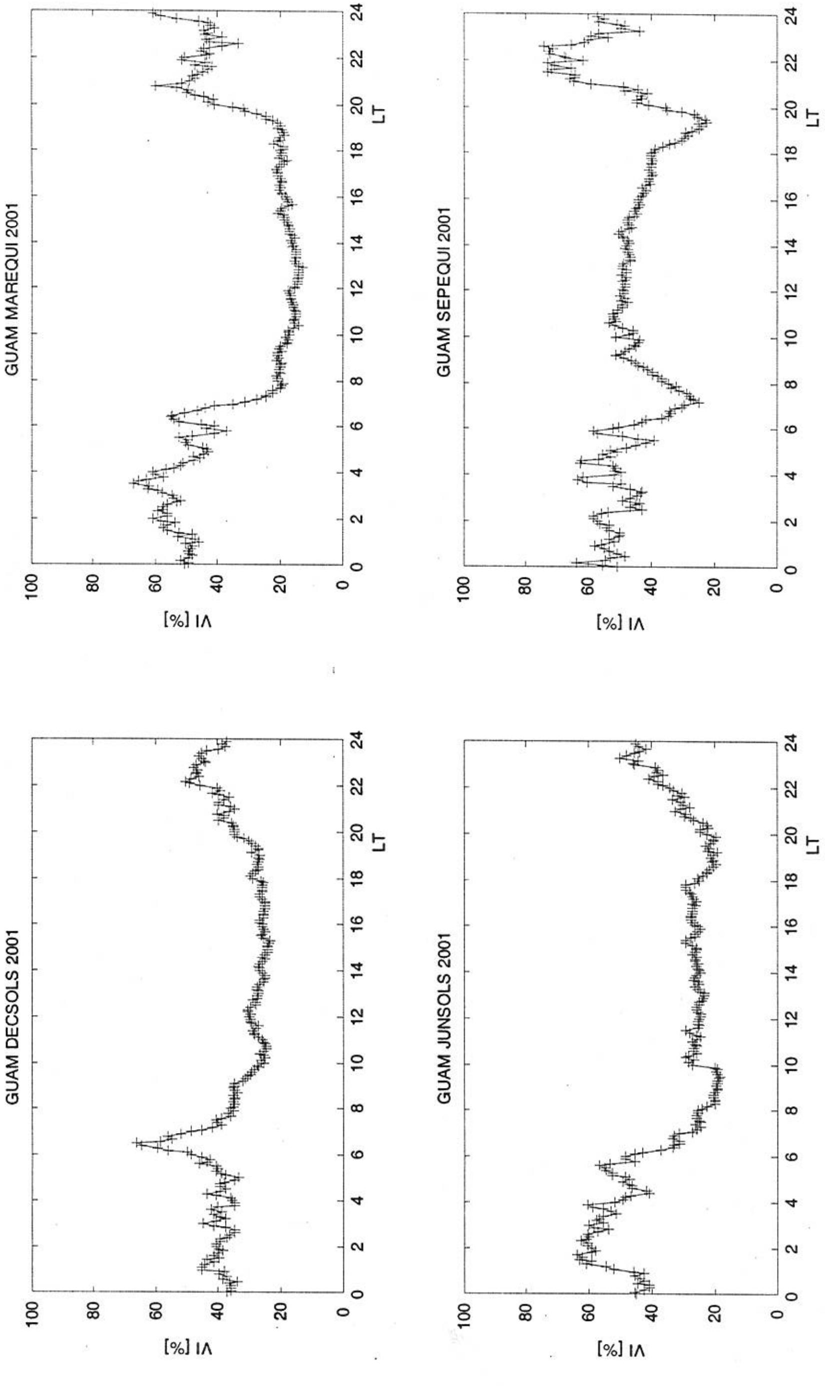

Figure 13: Variability index for GUAM during HSA

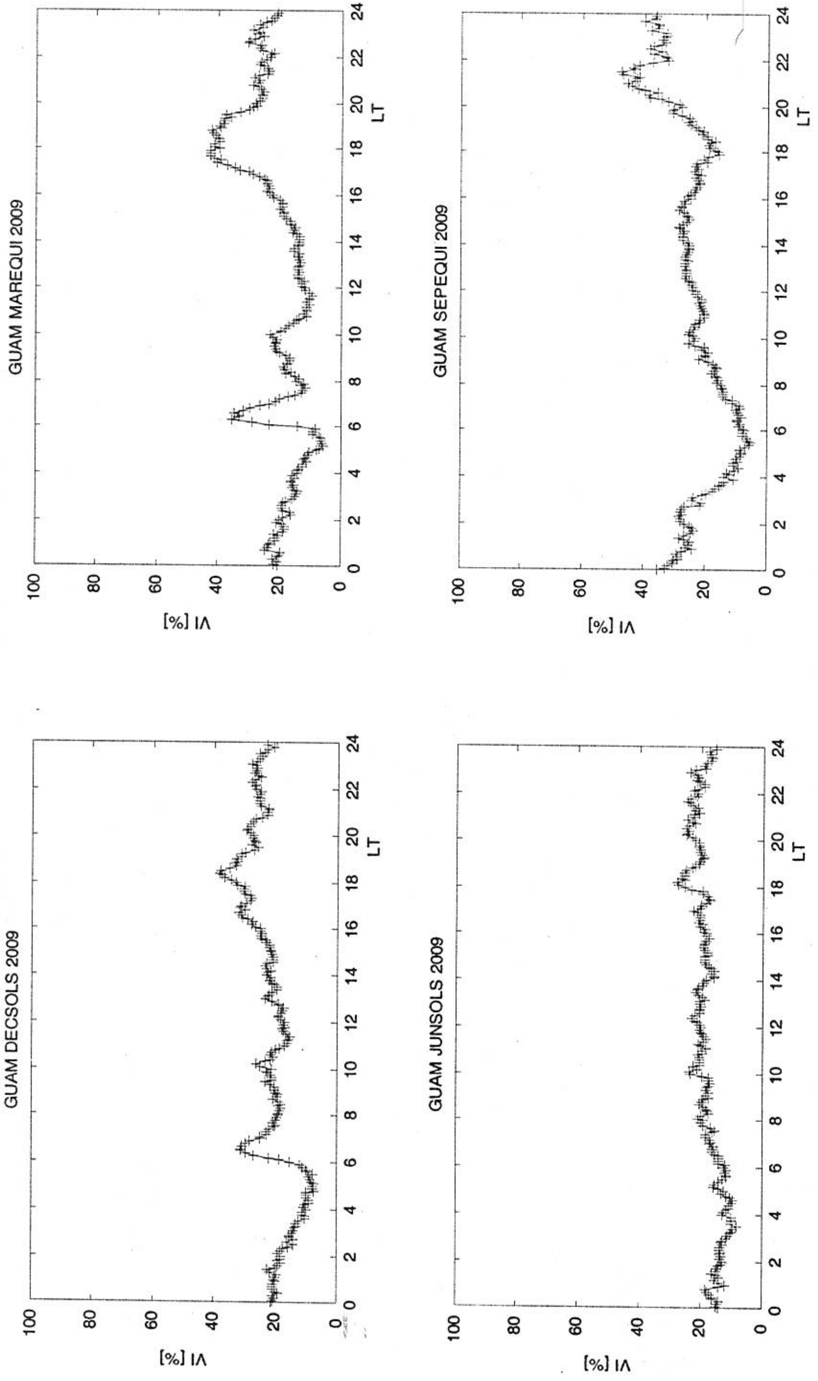

Figure 14: Variability index for GUAM during LSA

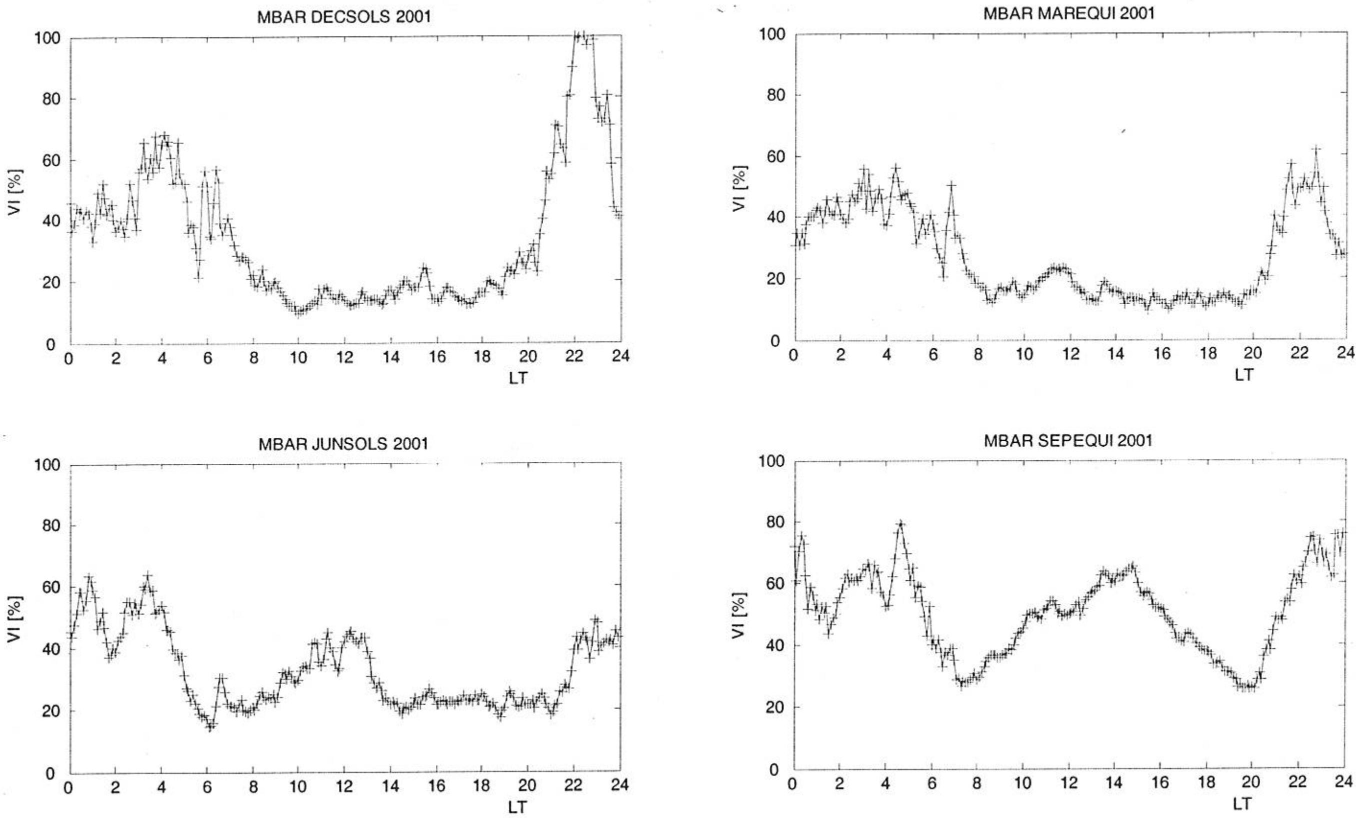

Figure 15: Variability index for MBAR during HSA

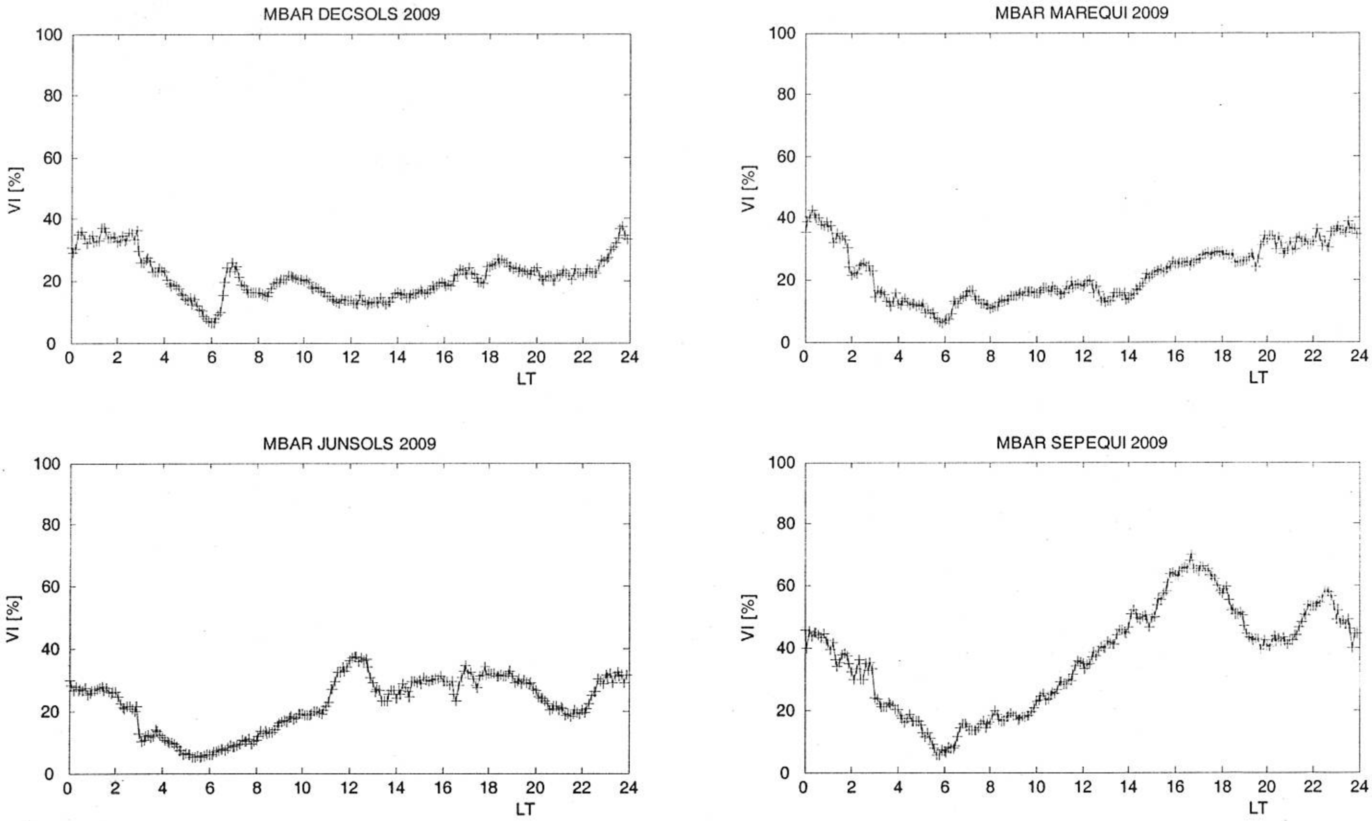

Figure 16: Variability index for MBAR during LSA